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A Method of Analyzing Complexity by Effects and Rapid Acquisition of the Most Ideal Solution Based on TRIZ

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Abstract

Presently, designers could only use definitions in the complexity theory to analyze the complex problems in the system. In the article, a new method is put forward which is the method of analyzing complexity by effects and rapid acquisition of the highest ideal solution based on TRIZ. By the twice mapping events of complex problems, transform them into chain of additional effects. Due to that some relationship exists between the ideal of module of additional effects' solution and S-curves, designers could rapidly obtain the most ideal solution. Finally, use the ultrasonic system examples to check the method.

Keywords:

Complexity, TRIZ, Additional effects, most ideal solution

1 INTRODUCTION

Complexity Theory based on Axiomatic Design[1] is one of the important theory of Problem Solving techniques. Designer analyze the system's complexity according to nothing more than the concept of the complexity presently. This paper puts forth a new method of analyzing the complexity by effects and Rapid Acquisition of the highest ideal Solution Based on TRIZ.

The essence of the design is to eliminate the complexity. There are several study performances for Complexity Theory based on Axiomatic Design. Suh[2] shows that designers are likely to use c/p transformation to reduce time-depended complexity. Liu[3] has investigated how to use TRIZ tools to reduce system's complexity. Zhang[4] propose that designers can reduce the complexity by a design model which combines Complexity Theory based on Axiomatic Design with evolution path in TRIZ. Since it is very important to eliminate the complexity of a system, it makes it a new problem. Designer will focus on the reducing the complexity in this study.

The goal of design is to satisfy the functional requirement. The functional requirement can be realized by its effects. Effect is one of the important concepts in TRIZ[5]. If the functional requirement can not be satisfied, the complexity can be analyzed by its effects. The method of analyzing the complexity by effects is advantageous not only to analyzing the complexity but also to obtaining the solutions which can reduce the complexity. However，the method brings some new problems to us. If there are many additional effects in the chain and each additional effect have several solutions, a large amount of time will be wasted on finding the TRIZ special solutions and it is difficult to find the highest ideal Solution. Among the designs available from the functional point of view, one may be superior to others in terms of achieving the design goals as expressed in the functional requirements[6]. However, the best design is usually hidden in the several TRIZ special solutions. A designer with years of experience may probably find a better solution. However， a designer, who is a freshman, may obtain a worse one. It is inappropriate that a designer could select the best one by his or her experience. In view of this problem, this paper put forwards a method of analyzing the complexity by effect and obtaining the highest ideal Solutions for reducing the system's complexity. A design example of ultrasonic system is presented to demonstrate the design process of complexity elimination.

2 COMPLEXITY THEORY

Suh put forth the Complexity Theory based on the Axiomatic Design method [1]. The design effort may produce several designs, all of which may be available in terms of functional requirements. It is likely that different designers will come up with different designs, because there can be many designs that satisfy the function requirement. However, one of these designs may be superior to the others. The Complexity Theory based on the Axiomatic Design is useful in selecting the best among those designs that are available. Among the designs that available from the functional point of view, one may be superior to others in terms of achieving the design goals as expressed in the functional requirements. The Complexity Theory based on the Axiomatic Design states that the design with the highest probability of success is the best.

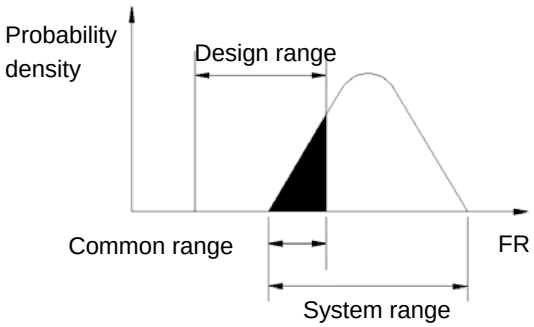

Figure 1: the relation among design range, system range and common range[1]

Suh states that Complexity is defined as a measure of uncertainty in achieving the functional requirements (FRs) of a system [1]. The overlap between design range and system range is called common range, which is shown in Figure 1.

Complexity is a function of the relationship between the design range and the system range [1]. A design is called complex when its probability of success is low, that is, when the information content required to satisfy the FRs is high. A physically large system is not necessarily complex if the information content is low. Conversely, even a small system can be complex if the information content is high[7].

3 A METHOD OF ANALYZING COMPLEXITY BY EFFECTS AND RAPID ACQUISITION OF THE HIGHEST IDEAL SOLUTION

3.1 The mapping of the complex problem

Complexity is the function of design range and system range[8]. According to the complexity theory, designers should determine in the functional domain whether there are complex problems exist in the system, which actually is a comparatively very difficult process. Due to the mapping relationship as zigzagging between functional domain and physical domain [8], designers could determine the complex problems in the system through its performance in the physical domain. Here, the complex problems can be defined in the physical domain as event of complex problems.

It is comparatively simple to obtain events of complex problems. Nevertheless, since the problem description by events of complex problems has comparatively large limitation, when obtaining solutions of events of complex problems, they can only be solved by applying knowledge processed by professional designers. Moreover, due to the limit knowledge, designers couldn't get solutions with high ideality , and even worse, without any solution sometimes.

To explicitly describe the complex problems of a system, designers should map the events of complex problem in physical domain into the ones in functional domain, the process of which is defined as the first mapping. After determining the (problem) function caused the complex problems of system, designers could apply TRIZ tools[9] to get solution of complex problems. The description of complex problems by function is comparatively clear. Therefore, knowledge that could be used is much wider compared with the condition of solving complex problems in physical problems. While, only a few TRIZ solutions could be get when adopting this method and it is possible that the ideal solution with highest degree can not be obtained. Due to the great difference between each solution, it is relatively difficult for designers to pick the ideal solution with the most ideal.

To easily getting more TRIZ solutions and choose the most ideal one from them, complex problems in the functional domain should be mapped as chain of additional effects, the process of which is called the second mapping of complex problems. The additional effect is put forward on the basis of effect concept in TRIZ. As an important concept, effect[10] is also an important method to realize the high level ideal solution of TRIZ. The effect that can meet the functional requirements is the ideal one, and chain of effects composed by ideal ones is called the chain of ideal effects[11]; effect that cause complex problems of system is the additional one, and the chain of effects composed by additional effects is named chain of additional effects. Usually, additional effect is caused by the following factors: noise, coupling, environment and random variables in the design parameters. General effect chains contain the ideal effect chains and additional ones, as shown in Figure 2.

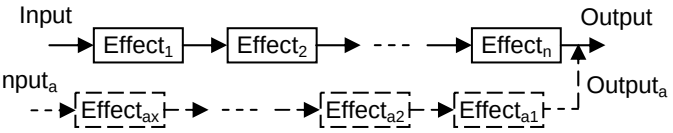

Figure 2: total chains of effects

Events of complex problems in physical domain are caused by problem functions in functional domain, while the ones in system are caused by additional effects. Complex problems in functional domain will be transformed into additional effect chains through the second mapping of complex problems, which is very favorable for obtaining TRIZ solution when getting the one of additional effect. The second mapping is input on the basis it's the first mapping. A new analyzing model of complex problem on the basis on effect will be established trough the first and second mapping of complex problems. The process of twice mapping of complex problems is shown as the Figure 3.

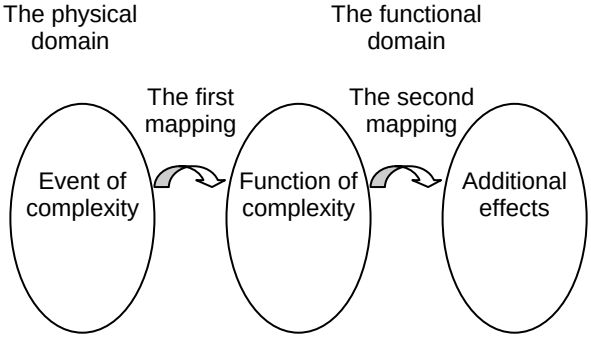

Figure 3: the twice mapping of complexity

3.2 A method of Analyzing Complexity by Effects

Additional effect

The purpose of design is to meet functional requirements while function could be expressed by its corresponding effect. Moreover, effect could be described by the relationship between input and output. If the functional requirements could not be reached, issues of complex problems in the structural domain could be mapped into corresponding additional effect chain through two-level mapping. The additional effect is the effect which causes the functional requirement can not be satisfied.

Relation sketch of additional effects

Complex problems in the system are induced by additional effects, while additional effects in the system always exist in the form of additional effect chains. The output of pre-level additional effect will affect its following one. Three basic relationships do exist between additional effects in additional effect chains [11], such as "and gate, or gate and not gate" as shown in the Figure 4. The relationship sketch of additional effects composed by these three basic relationships is also shown in the Figure5.

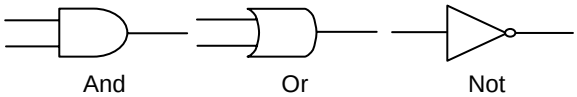

Figure 4: three kinds of relationship of additional effect

In the sketch, input and output contents are all corresponding information content. When information content of some additional effect is "1", it means that this effect will affect the following one. On the contrary, when the content of some additional effect is "0", the following one will not be affected by this. Additional effects will lead to complex problems of system. According to the additional effect relationship sketch, at least one of the total input of

additional effect sketch in the system that exists complex problems is “1”, which the total output is also “1”. The process of applying additional effect relationship sketch to analyze complex problems of a system is actually the very one of transforming the total output from “1” to “0”.

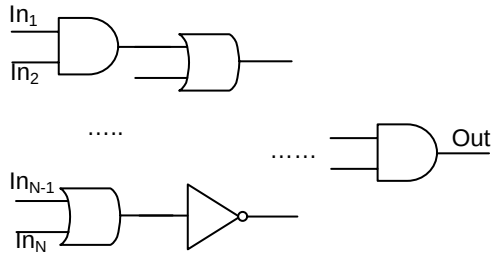

Figure 5: The relation sketch of additional effects

In chain of additional effects, the output of additional effect is only relative to its input and its own additional effect, the input content is the pre-level information content. The output content of additional effect is the information content of present level. The input value is “1” when some level additional effects are affected by the previous ones; or the input value will be “0” if the additional effects are not disturbed by the previous ones. Due to the existence of complex problems in the system, total input and output of additional effect chains will be both “1”. Additional effect chains will be applied to analyze complex problems in system, which namely is the process of transforming total output of additional effect chains from”1” to “0”. If every output of additional effect in additional effect chains is “0”, then, total output of additional effect will be “0”. Nevertheless, when getting solutions for each additional effect in additional effect chains and making its output “0”, though total output of additional effect chains will be “0”, and additional effects of the system will be eliminated, complex problems in the system will also be solved accordingly. Actually, it takes a lot of time of designers.

Module of additional effects

To get every solution of each additional effect in additional effect relationship sketch will cost a large amount of time. Therefore, additional effect chains could be divided into sequently arranged modules of additional effects, as shown in the Figure 6. Among them, the ones on bottom of additional effect chains is called bottom module of additional effects, which is close to the total output of additional effects. Moreover, the one on top of additional effect chains is called top module of additional effects. They are close to total input of chain of additional effects.

It is helpful for designers to solve complex problems when bringing in module of additional effects. When dividing module of additional effects, following principles must be paid attention to:

1. The entire input of chain of additional effects is from top module of additional effects.

2. The entire output chain of additional effects is from bottom module of the additional effects.

3. The output of pre-level module of additional effects will affect the following one’s input.

4. The output of module of additional effects is only relative to their own additional effect and input of module of additional effects.

5. Complex problems will be eliminated when total output of chain of additional effects is “0”.

It is not necessary to get TRIZ solution of every additional effect in chain of additional effects for designers after obtaining module of additional effects according to the above mentioned principles. When the output of some modules of additional effects are all changed from “1” to “0”, both input and output of the following level modules of additional effects will be changed into “0”. Similarly, after transmitting from one level to another, finally, total output of chain of additional effects will change to “0”. Therefore, the complex problems of a system will be solved if designer could get TRIZ solution of any module of additional effect. But usually, many modules of additional effects will exist in chain of additional effects and each one has many solutions. Therefore, it has become an urgent problem to help designers rapidly obtaining the best solution. In this article, designer put forward the method of rapidly get the method of analyzing complexity by effects and rapid acquisition of the highest ideal solution based on TRIZ.

3.3 Method of Rapid Acquisition of the highest ideal Solution

The method of analyzing complexity by effects is not only favorable for analyzing complex problems, but also for favorable for obtaining solutions of eliminating complex problems in the system. However, the method also brings in some new problems. If there are many additional effect modules in additional effect chains and each one has a lot of solutions, to obtain all TRIZ solutions will take a large amount of time, and it’s also very difficult to fin the best solution. Ideal result[12] is an important concept inTRIZ. An important principle of TRIZ theory is to enhance the ideality of a system. The degree is defined as[13]:

$$\text{Ideality} = \sum \text{Benefits} / (\sum \text{Costs} + \sum \text{Harm}) \quad (1)$$

In view of this problem, this paper put forwards a method of obtaining the highest ideal Solutions of the method of analyzing complexity by effects. Designers could rapidly obtaining the highest ideal solution of eliminating complex problems in the system through the distribution relationship of the ideality of solutions of different additional effect modules in additional effect chains and the difference of ideality between different solutions of the same additional effect.

The ideality distribution of solutions of addtional effect modules is one of an important reserach part to the method of obtaining the highest ideal Solutions. According to the ideality of TRIZ solution, it includes : low-level ideal result (LIR), intermediate-level ideal result (IIR), high-level ideal result (HIR), and ideal final result (IFR), etc[5]. The low-level ideal result is to eliminate the complexity of the system by using resources outside the system, while the intermediate-level ideal result is to eliminate the complexity by using the resources inside. The high-level ideal result refers to

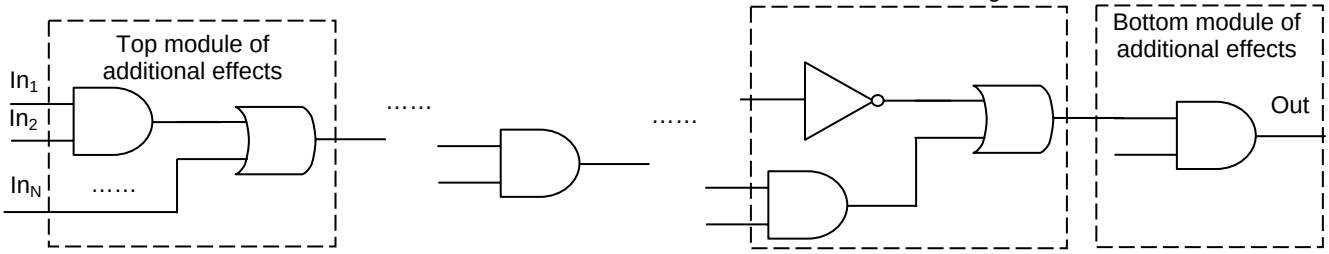

Figure 6: The relation graph of additional effects and the modules of additional effects

eliminating the complexity of the system by using the resources within special field. The ideality of this kind of solution is higher than others and this kind of solution approach the final results (IFR). Products are carriers of functions. In TRIZ, s-curve is used to describe the ideality of products.TRIZ solutions obtained according to additional effects is also to meet the functional requirements of the system. Therefore, for TRIZ solutions of the same additional effect, its ideality distribution also comply with S-curve regulation. Ideality distribution of TRIZ solution of additional effect is shown as Figure 7.

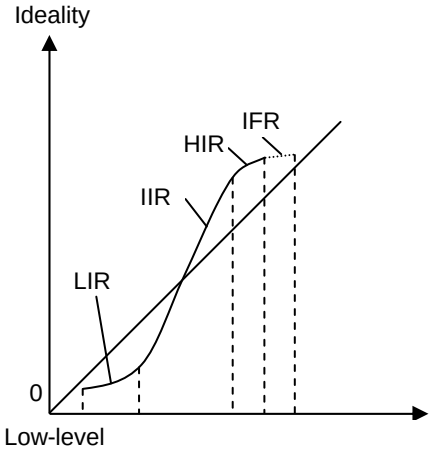

Figure 7： the distribution of the ideality of the same module of additional effects' solutions

Solutions of module of additional effects also comply with S-curve regulations. Solution of the additional effect with the highest ideality could be obtained accroding to its ideality.Due to the fact that so many modules of additional effects exist in the chain additional effects, it will take a large amount of time if designer are going to get solutions for every addtional effect module and compare their ideality. Then, how to get the solution with the most ideal in the whole chain of additional effects ? How the ideality of solutions of different modules of additional effects is distributed ?

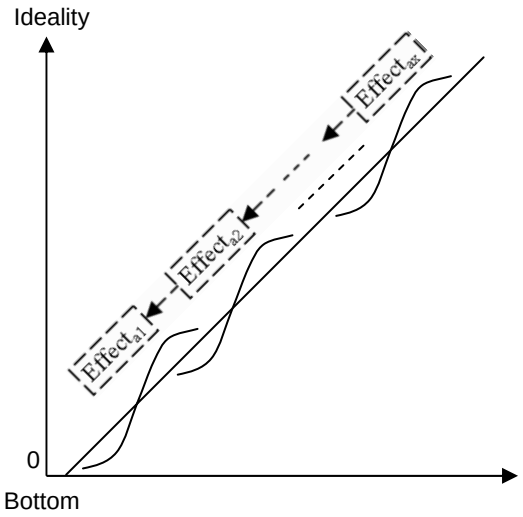

Figure 8： a group of s-curve and the ideality of additional effect's solution

According to the principle of obtaining additional effect modules, it is found that there is close relationship between them. Any solution of a random a module of additional effect designers get could be used to eliminate the complexity of a system. By obtaining TRIZ solutions of module of additional effects to eliminate complex problems of a system can be transformed into getting solutions from a function. Product Evolutionary in TRIZ, products with the same functions under different effects follow the S-curve regulations. The process of obtaining solutions of modules of additional effects in chain of additional effects is similar to that of product evolutionary, which are both to realize the process of obtaining solutions of the same functions and different effects. Module of additional effects also comply with S-curves regulations. Therefore, the ideality of solutions of pre-level additional effect modules are higher than the corresponding ones of the following. The relationship between module of additional effects and group of S-curves is shown as Figure 8.

According to the group of s-curves, HIR is comparatively a better solution in additional effect modules. If there are many modules of additional effects in the chains of additional effects, since the ideality of solutions of bottom module of additional effects is lower than that of top module ones, namely, the top ones are more ideal , there is no need to get solutions of bottom module additional effects if there are already solutions of top ones.

When the modules of additional effects are obtained in the chain of additional effects, designers need not find every modules of additional effect's solutions. Designers can find solutions of the top module of additional effect .If the top module of additional effects can find no the TRIZ special solutions, designers will try to find solutions to the next module of additional effects in the direction from the top module of additional effects to the bottom module of additional effects.

There is no need to get solutions of every module of addtional effect if designers have already get the additional effect modules in chain of additional effects. The only thing is to obtain solutions of top module of additional effects. If there is no solution of this module of additional effect, designer will turn to the next along the direction from top module of additional effects to the bottom ones. Figure 9 shows the process of obtaining the highest ideal solution.

By adopting the method of rapid acquisition of the highest ideal solution, designer could not only get the best solution of eliminating complex problems, but also have no need to get all TRIZ solutions as well as to calculate the ideality of all solutions. Therefore, it is relatively easy to get best solution by using this method and saves much time.

3.4 A design process

In the article, a new method is put forward which is the method of analyzing complexity by effects and rapid acquisition of the highest ideal solution based on TRIZ. Now, practical examples of ultrosonic system will be used to check the method. Six steps need to be followed :

Step1 : Descripe complex problems in physical domain. To descripe complex problems by events of complex problems.

Step2 : Carry out the first mapping of complex problems. To transform events of complex problems in physical domain into problem functions.

Step3 : Carry out the second mapping of complex problems. To transform functions of complex problems into chain of additional effects.

Step4 : Determine the additional effect relationship sketch according to the relationship between additional effects.

Step5 : Determine additional effect modules by dividing principes of module of additional effects.

Step6 : Get the solution with the highest ideal solution of eliminating complex problems according the method of rapid acquisition of the highest ideal solution of complex problems.

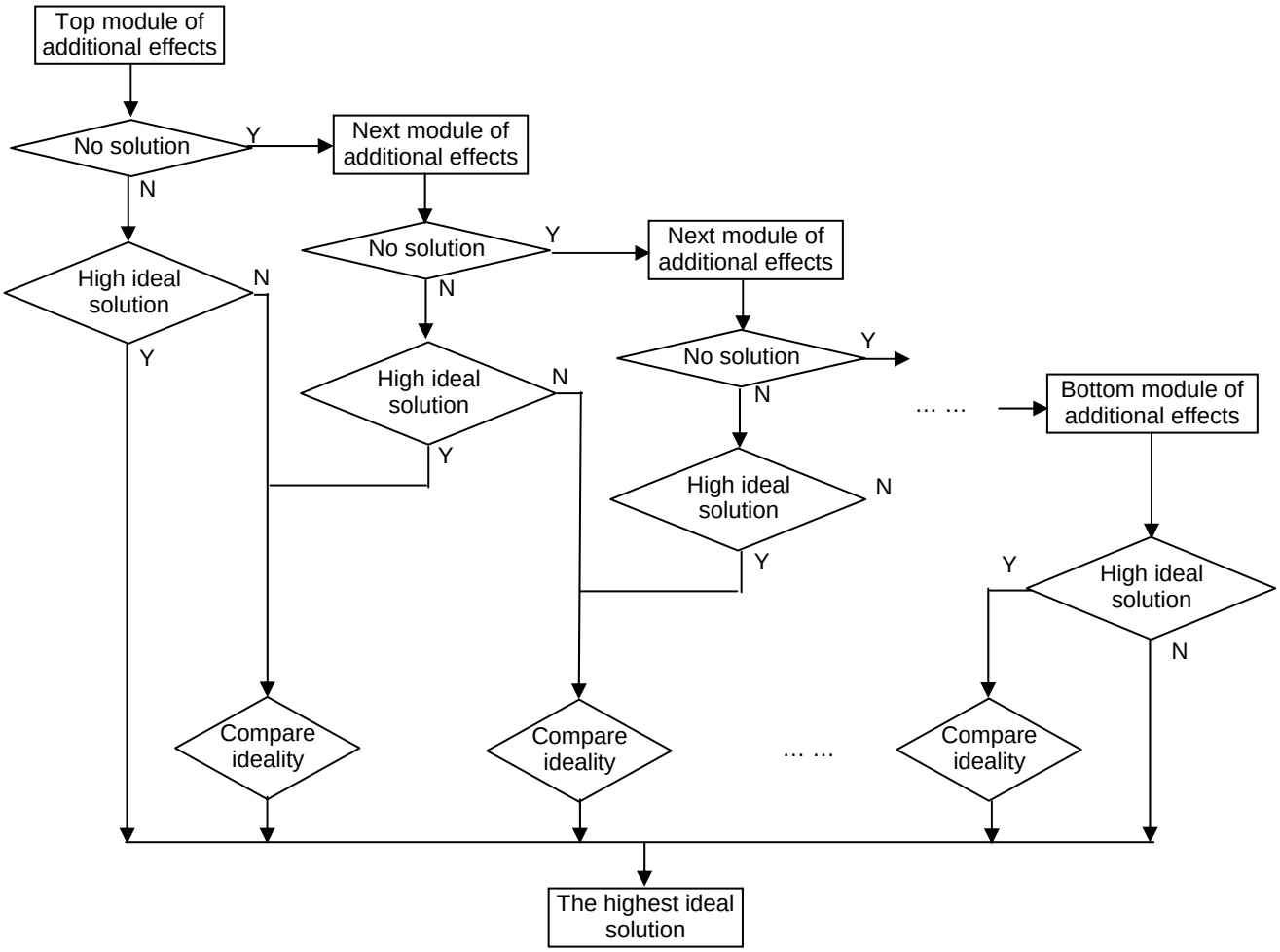

Figure 9: The process of obtaining the highest ideal solution

4 A CASE STUDY

Fig.10 is the working principle of an ultrasonic system. These devices transmit a short burst of ultrasonic sound toward another sencor, which reflects the sound back to the sensor[14]. The system then measures the time for the echo to return to the sensor[15].

The ultrasonic system includes the ultrasonic sensors, the water tank, the intake pipe, and the outlet pipe. If water is static in the pipe, the ultrasonic sensors measure the time for the echo to the other sensor. However, when water is flowing in the pipe, the ultrasonic signal becomes smaller and smaller untill the ultrasonic signal disappeared. For the system could not satisfied the functional requirements, there is a complex problem in the ultrasonic system. The method of analyzing the complexity by effects and Rapid Acquisition of the highest ideal Solution Based on TRIZ can be used to analyze this system.

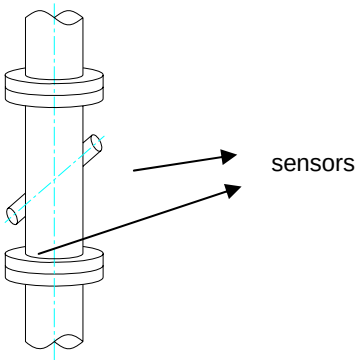

Figure10： the ultrasonic system

Step1: Describe complex problems in physical domain. To descripe complex problems by events of complex problems. If water is static in the pipe, the ultrasonic sensors are working. However, when water is flowing in the pipe, the ultrasonic signal becomes smaller and smaller untill the ultrasonic signal disappeared. Even if water comes to rest in the pipe, the ultrasonic sensors are not woring, too. When the ultrasonic sensors take out water and lay them in water again, the ultrasonic sensors can not woring, too. For the ultrasonic sensors in liquid have a frequency in excess of 100,000 cycles per second (hertz)[16]. If the ultrasonic sensors in liquid are propagated in air, the ultrasonic signal diminishes.

Step2: Carry out the first mapping of complex problems. To transform events of complex problems in physical domain into problem functions. The reason why the system can not satisfy the functional requirement is that the ultrasonic signal is decreased when it transits the gas. There are little gas bubbles on the ultrasonic sensors when water is not flowing in the water tank. When water is flowing, the gas bubbles become more and more on the ultrasonic sensors while the ultrasonic signal becomes smaller and smaller. At last, the ultrasonic sensors can not work. Even if water comes to rest in the water tank, the ultrasonic sensors can not work because the gas bubbles are still on the ultrasonic sensors. The ultrasonic sensors are out of water where are little gas bubbles on the ultrasonic sensors. When the ultrasonic sensors are put in water again, the ultrasonic sensors are working. Figure 11 shows the gas bubbles on the ultrasonic sensors.

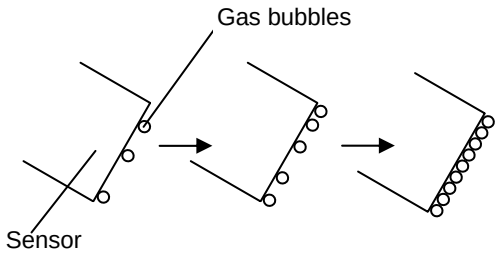

Figure 11: the gas bubbles on the ultrasonic sensors

Step3: Carry out the second mapping of complex problems. To transform functions of complex problems into chain of additional effects.Accoring to the results of the first mapping of complexity, there are two additional effects which are the Gravity effect and Agglutination effect in chain of additional effects.

Step4: Determine the additional effect relationship sketch according to the relationship between additional effects. Figure 12 shows the relation sketch of additional effects of the ultrasonic system.

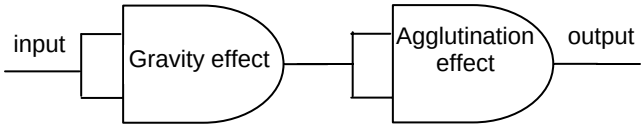

Figure 12: the relation sketch of additional effects of the ultrasonic system

Step5: Determine additional effect modules by dividing principes of module of additional effects.The gravity effect is the top module of additional effects and the agglutination effect is the bottom module of additional effect. Figure 13 shows the modules of additional effects in the ultrasonic system.

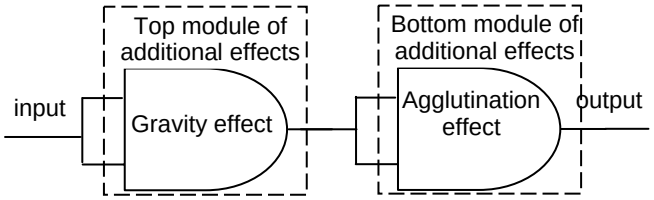

Figure 13: the modules of additional effects

Step6: Get the solution with the highest ideal solution of eliminating complex problems according the method of rapid acquisition of the highest ideal solution of complex problems.

For the gas bubbles rise in water by universal gravitation, the gas bubbles arise from water and are assembled on the ultrasonic sensors. Designer can obtain two solutions which are the project one and project two. The project one, which install the ultrasonic sensors where it has difficulty in assembling the gas bubbles on the ultrasonic sensors, can eliminate the gravity effect which is one of modules of additional effects. Fig.14 shows the project one. The project two, which shows as Fig.15, is a device which is an acoustic wedge can ward off the gas bubbles.

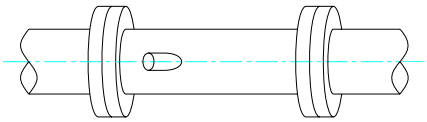

Figure 14: the project one

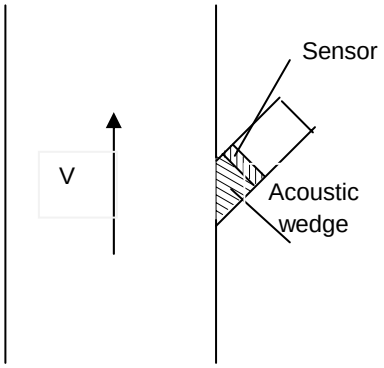

Figure 15: the project two

The TRIZ special solution, whose ideality is the highest, is the best. Designer can obtain two TRIZ special solutions which eliminate the complexity of the ultrasonic system. The project one is a high-level ideal result because it uses the resource in special field to eliminate the complexity of the ultrasonic system. The project two is a low-level ideal result because it uses the resource out of the system. For the project one eliminates the gravity effect which is the module of top nmodules of additional effects, the project one, whose ideality is the highest, is the best.

According to the method of analyzing the complexity by effects and rapid acquisition of the highest ideal solution based on TRIZ, designers can obtain the highest ideal solution which is the project one. To prove that the project one is the highest ideal solution among the TRIZ solutions which can reduce the complexity of the ultrasonic system, designer will obtain the solutions which are the Agglutination effect's. Subsequently, designer can determine whether or not the project one is the highest ideal solution among the solutions.If designer can remove the gas bubbles where are on the ultrasonic sensors, designer can eliminate the agglutination effect which is another additional effect. Designer can obtain two solutions which are the project three and project four. The project three, which shows as Fig.16, is a device that the ultrasonic sensors have its coat of nano-paint which it has difficulty in assembling the gas bubbles. The project four , which shows as Fig.17,is to design an eraser that can remove the gas bubbles on the ultrasonic sensors.

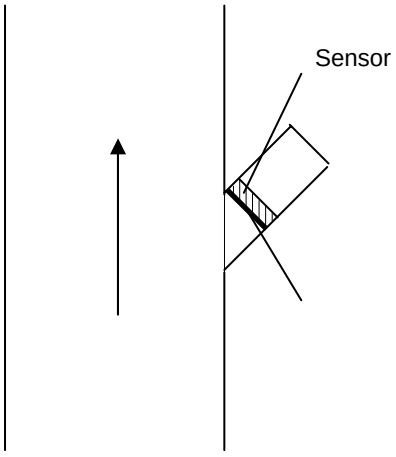

Figure 16: the project three

According to the ideality classification of TRIZ solutions, the project one is a high-level ideal result of the top module of additional effect because it uses the resource in special field to eliminate the complexity of the ultrasonic system. The project two is a low-level ideal result of the top module of additional effect because it uses the resource out of the system. The project three is an intermediate-level ideal result of the Agglutination effect because it uses the

resource in the system. The project four the Agglutination effect is a low-level ideal result because it uses the resource

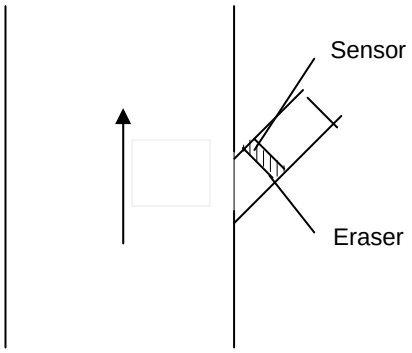

Figure17: the project four

out of the system. For the ideality of the project one is the most ideal among all TRIZ solutions,project one is the best.

5 CONCLUSIONS

The case study results show that the method can help designers to solve the complex problem of the ultrasonic system. Designers obtain the highest ideal solution by using method of analyzing the complexity by effects and Rapid Acquisition of the highest ideal Solution Based on TRIZ. The twice mapping of complexity and the distribution of the ideality of additional effects' solutions are first put forward. At last, a design example of ultrasonic system is presented to demonstrate the method of analyzing the complexity by effects and Rapid Acquisition of the highest ideal Solution Based on TRIZ.

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